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Pacific Region

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Science Response 2017/038

ASSESSING THE RISK OF SHIP STRIKES TO HUMPBACK (*MEGAPTERA NOVAEANGLIAE*) AND FIN (*BALAENOPTERA PHYSALUS*) WHALES OFF THE WEST COAST OF VANCOUVER ISLAND, CANADA

Photo credit: John Ford, DFO

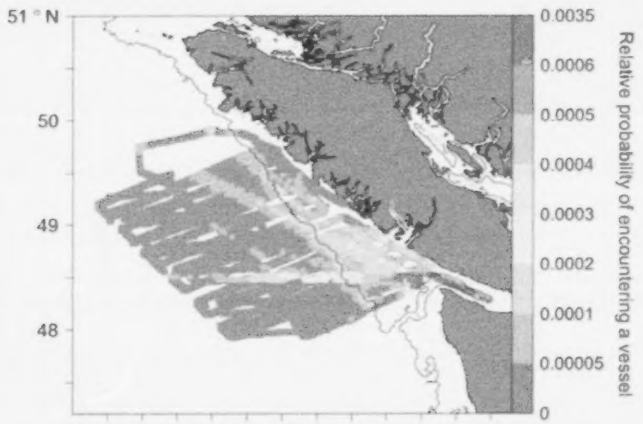

Figure 1. Relative probability of encountering a large vessel (e.g. tanker, cargo ship, cruise ship) travelling at > 5 knots in the study area off the west coast of Vancouver Island, BC, Canada. The black line represents the continental shelf break (200 m depth contour).

Context:

Vessel collisions with whales have been identified as a key threat to the recovery of humpback whales (Megaptera novaeangliae), fin whales (Balaenoptera physalus), blue whales (Balaenoptera musculus), North Pacific right whales (Eubalaena japonica), and sei whales (Balaenoptera borealis) in British Columbia. These species are listed under the Species-at-Risk Act (SARA) as 'Special Concern' (humpback), 'Threatened' (fin and sei) or 'Endangered', (blue and right). DFO SARA Program requested that DFO Science provide advice regarding methods to assess the threat from ship strikes and to provide estimates of the risk of mortality to large baleen whales off the west coast of Vancouver Island. Results of the assessment and advice will assist both the SARA program and the Fisheries Protection Program when considering potential impacts to species and habitats arising from projected increases in shipping traffic, and will provide information for consideration in the development and management of a protected areas network. This Science Advisory Report is from the February 24th, 2016 National Marine Mammal Peer Review Committee (NMMPRC): Part II meeting. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Baleen whales are at greater risk of being struck by large ships than other marine mammals because of their large body size, limited ability to manoeuvre away from oncoming vessels and because of behavioural characteristics that likely contribute further to their vulnerability.
- Southwest Vancouver Island, Canada is the approach corridor to major ports. The route into and out of Juan de Fuca Strait is regularly transited by large, deep sea vessels. Studies have demonstrated that strikes from ships travelling at speeds exceeding 12 knots are likely to cause mortality, whereas strikes from ships travelling at speeds ≥18 knots are almost certain to be fatal.
- The spatial distribution of whales and ship traffic was compared to identify areas where strike risk is greatest. Risk was expressed as the relative probability of a ship and a whale occurring in the same "space". Ship speed was used to calculate the probability that a collision would be fatal to a whale.
- During 2012 through 2015, 34 systematic aerial surveys were conducted in fall and winter to predict relative densities of humpback and fin whales over a region overlapping the shipping corridor off the west coast of Vancouver Island.
- Humpback whales were primarily observed on the continental shelf, with highest occurrence along the shelf edge (~200 m depth contour), fin whales were observed to occur off the shelf in deeper water (>400 m depth).
- Blue whales are also vulnerable to ship strike, but their distribution could not be quantified because of very low numbers of sightings.
- Ship traffic density and speed in the study area was available in a spatially compiled format for an entire year (2013).
- For humpback whales, the highest risk of whale-ship encounters (strikes) was predicted to occur along the continental shelf break at the 200 m depth contour, and inside western Juan de Fuca Strait. For fin whales, the regions of highest predicted risk were in a corridor offshore of the shelf break and west of the entrance to Juan de Fuca Strait, as well as inside western Juan de Fuca Strait.
- The mean probability of a fatal collision was predicted to be slightly higher for fin whales than humpback whales even though fin whales occurred at much lower densities than humpback whales. This is likely related to the primarily offshore distribution of fin whales, which exposes them to marine traffic travelling at higher mean speeds.
- Ship strike mortalities in British Columbia may have a greater impact on fin whales because the population is smaller than the humpback whale population and because they are present year-round.
- Even in the areas of highest predicted risk for whale-ship strikes, the estimated probability was less than a 1% chance for either species. However, the impact of this risk on the populations cannot be determined until the abundance of these species in the study area is known.
- The ship strike models likely underestimate true collision risk because they did not take into account possible species-specific differences in vulnerability.

- It is reasonable to expect that the future risk of ship strikes will increase in the study area as a result of greater traffic, larger ship sizes, and growing whale populations. However, it is not possible to estimate future risks without having more specific information on the factors influencing risk.

BACKGROUND

Baleen whales are at greater risk of being struck by ships than other marine mammals because of their large body size and limited ability to manoeuvre away from oncoming vessels. Furthermore, these species often spend extended periods of time at or near the surface, either feeding or recovering from the energetic demands of lunge-feeding at depth, which makes them more vulnerable to vessel strikes. Ship strike risk to baleen whales is higher at night, both because ship operators cannot visually detect whales and because planktonic prey migrate toward the surface at dusk, resulting in increasingly shallow feeding dives in some baleen whale species. These daily shifts in dive behaviour, which are typical of most baleen whales, place them within the draft depths of oncoming vessels. Many cargo ships and tankers (which are often greater than 300 m long with beams exceeding 40 m) have hulls reaching depths of 8-18 m and due to the hydrodynamic forces around a moving ship, the lethal strike zone can extend 1-2 times beyond a ship's actual draft (Silber *et al.* 2010). Worldwide, fin whales are the most frequently reported species struck by vessels. Studies have demonstrated that strikes from large ships travelling at speeds exceeding 12 knots are likely to cause mortality, whereas strikes from ships travelling at speeds ≥18 knots are almost certain to be fatal.

Direct measures of the frequency of ship strike underestimate the extent of these occurrences. This is particularly true in offshore waters, where incidents and carcasses often go undetected because the impact of a whale contacting the hull of a large ocean-going ship is not felt and because the ship bow is not visible to the crew. Lethal strikes of species with primarily offshore distributions, such as fin whales, are probably especially prone to under-reporting. Reported ship strikes are biased heavily towards nearshore areas where there are relatively more coastal mariners on the water (operating smaller vessels) likely to observe a carcass or observe an incident.

To identify areas of greatest risk, the spatial overlap between whale populations and shipping traffic must be determined. Spatial assessment of variation in average vessel speeds is also critical to identifying areas where strikes are most likely to be fatal. Information about ship strike risk in the offshore areas west of Vancouver Island is particularly vital given the potential biases in reporting of incidents and the high use of this region by marine traffic, particularly by large commercial ships transiting Juan de Fuca Strait, a major shipping channel regularly transited by large, deep sea vessels destined for one of several large ports (Vancouver, Seattle, and Tacoma). Between 10,000-11,000 vessels of all types enter this confined waterway every year.

Spatial models combining whale distributions and shipping data provide a means of predicting ship strike risk over large areas and identifying the regions of highest conservation concern, particularly in offshore areas. This analysis addressed strike risk for the two most frequently observed species of large baleen whales in BC, humpback whales and fin whales.

ANALYSIS

Methods

We used systematic aerial survey data (2012-2015) to predict whale densities off southwest coast Vancouver Island. We overlaid these predicted whale densities with an Automatic

Identification System (AIS) marine traffic dataset (2013) to calculate the relative risk of both vessel strikes and collision mortalities over a gridded 1 km x 1 km surface of the study area. In addition, we assessed the effect of future maritime traffic projections on relative ship strike risk to investigate the minimum likely increase in risk as a result of anticipated future fleet and port expansions.

Whale sightings data

Whale surveys were conducted from a De Havilland DHC-8-102 Dash-8 aircraft that flew along systematically placed transect lines at a nominal speed of 278 km h-1 (150 knots) and an altitude of 305 m (1000 ft). Transects ran in a northeast to southwest direction, roughly perpendicular to the west coast of Vancouver Island, BC, Canada at intervals of approximately 16 km. Two observers, positioned at special large observation windows aft of the cockpit (left and right), reported all whale sightings to a data recorder via radio headsets.

Vessel traffic data

The spatial distribution of marine traffic throughout the study area was available for 2013 at a resolution of 1 km x 1 km for all compulsory Automatic Identification System (AIS)-reporting ships. These vessels are ships other than fishing vessels ≥500 gross tons (GT), ships ≥300 GT transiting international boundaries, and ships ≥150 GT travelling internationally and carrying >12 passengers. These ships can be categorized as follows: cargo ships (e.g., container ships, bulk carriers), tankers, passenger ships (e.g., cruise ships, ferries), tug and tow, fishing vessel, and pleasure vessels (Simard *et al.* 2014). Cargo ships, tankers, and passenger vessels are of most concern when assessing ship strike risk to whales, given the typically greater size and speed of these vessel types.

Relative probability of a whale-vessel encounter

Determining the relative probability of a ship strike required estimates of the relative probability of encountering whales and the relative probability of encountering vessels in each grid cell.

Predicted densities of humpback and fin whales from the aerial survey sightings were estimated over a 5 km x 5 km grid of the study area using generalized additive models (GAMs). Relative whale encounter probabilities were then calculated at a 1 km^2 resolution by dividing whale density for each 1 km x 1 km grid cell (interpolated from model predictions at 25 km^2 resolution) by the summed densities of whales across all grid cells. The relative probability of encountering a ship in each 1 km x 1 km grid cell was calculated as the annual average of daily ship hrs/km^2 relative to the sum of ship hours/km^2 for all grid cells in the study area.

We estimate the probability of a ship strike by multiplying the probability of whales in a grid cell by the probability of ships in the same cell divided by the sum of probability of whales in all grid cells multiplied by the sum of probability of ships in all grid cells.

Risk of a lethal strike based on ship speed

To estimate the probability that a ship strike would result in mortality, we multiplied the probability of a whale and ship encountering each other in a 1 km x 1 km grid cell by an estimate of the consequence, which was the probability that the strike would be fatal as a result of vessel speed (Conn and Silber 2013).

To identify areas with the highest relative risk of collisions and mortality due to collisions, we extracted the grid cells representing the 95th percentile of the probability of a ship strike and the probability that a ship strike would be fatal for both humpback and fin whales, and compared these regions to the remainder of the study area.

Projected increase in marine traffic and future ship strike risk

The AIS ship traffic data set represents the intensity and speed of marine traffic in 2013. To predict future traffic, we used data tabulating the number of ships at present and the projected increase in ships to calculate the relative change in the number of ships by speed and category in the study area over the next one to two decades.

Results and Discussion

Vessel traffic data

Shipping traffic became much more concentrated as it funnelled into or out of Juan de Fuca Strait (Figure 1). A commonly transited route was apparent that began offshore (around latitude 48.5° N and longitude 128.0° W) and became more heavily used by ships as they moved eastward, toward the entrance of Juan de Fuca Strait and its Traffic Separation Scheme lanes. AIS reporting traffic in 2013 (excluding the slowest 2-5 knot speed category and cells without traffic) travelled at mean speeds per cell exceeding 12 knots throughout most of the study area. Vessel speeds were the highest (≥16 knots) near the continental shelf break (200 m depth contour) at the northern end of the study area, offshore of the shelf break, and inside western Juan de Fuca Strait. Regions with average vessel speeds ≤10 knots were limited, and primarily occurred closer to the Vancouver Island shore.

Aerial survey data

Aerial surveys were conducted on 34 days from 2012-2015, totalling 21,801 km of survey effort. The majority of surveys took place in the fall and winter months, with the greatest number occurring in September. A total of 160 humpback whale or 'like humpback whale' sightings (330 individuals) and 74 fin whale or 'like fin whale' sightings (120 individuals; Figure 2) were input into the GAMs. Mean group size per sighting for humpback whales was 2.1 ± 3.5 individuals (range = 1-33), and mean group size for fin whales was 1.6 ± 1.0 individuals (range = 1-5). There were also three sightings of single blue whales, all of which were observed west of the continental shelf break (200 m depth contour).

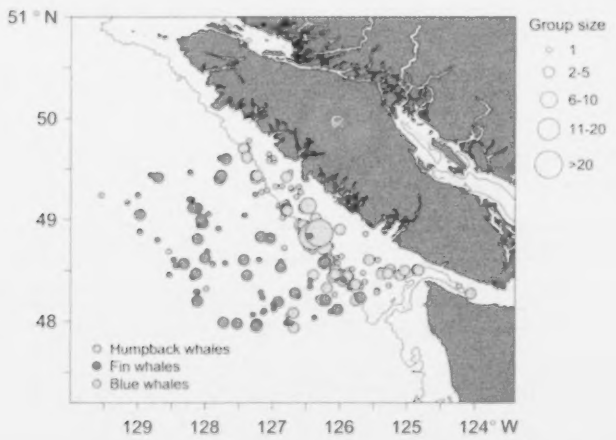

Figure 2. Locations of large whale sightings (N=237) by species and group size (range = 1-33), observed during aerial surveys off the west coast of Vancouver Island (2012-2015). The continental shelf break is illustrated by the 200 m depth contour (black line).

Whale Distribution Model

The model predicted mean densities of 0.008 ± 0.014 individuals/km^2 for humpback whales and 0.003 ± 0.002 individuals/km^2 for fin whales. The highest densities of humpback whales (max = 0.085 individuals/km^2) were predicted where depths of ~200 m occurred, which represents western Juan de Fuca Strait and the edge of the continental shelf. Along the shelf edge, higher densities of humpbacks were predicted at the lowest latitudes in the study area (~48.1°), and at intermediate latitudes (~49.3°). The highest densities of fin whales (max = 0.005 individuals/km^2) were predicted to occur west of the continental shelf edge, in water depths exceeding 400 m. Fin whale densities were very low inshore of the shelf break. Relative encounter probabilities for humpback and fin whales, derived from these model-predicted densities, are shown in Figures 3a & 3b.

Relative probability of a ship strike

The mean relative probability of a vessel encountering a whale (a ship strike) off the west coast of Vancouver Island was $4.2 \times 10^{-5} \pm 23.8 \times 10^{-5}$/km^2 for humpback whales and $4.2 \times 10^{-5} \pm 6.3 \times 10^{-5}$/km^2 for fin whales (Figures 3c & 3d). However, the average relative probability of a humpback whale being struck by a ship in the highest risk areas (i.e., 95th percentile of strike risk, representing the continental shelf break, western Juan de Fuca Strait and its inshore approaches) was 32.3 times greater than the mean relative probability of ship strike for humpbacks throughout the rest of the study domain. Fin whales in the highest risk areas (95th percentile of strike risk, including western Juan de Fuca Strait and its offshore approaches) had a 7.7-fold increase in the mean relative probability of being struck compared to other locations in the study domain.

Risk of a lethal strike based on ship speed

Among the areas where ship strikes were predicted most likely to occur, we estimated that a whale would have a 65% (humpbacks) or 69% (fin whales) chance, on average, of being killed when struck, compared to a 55% chance elsewhere in the study domain. Fin whales were more vulnerable on average to fatal ship strikes as a result of the higher speeds of shipping traffic transiting their offshore habitat.

Projected increase in marine traffic and future ship strike risk

Using estimates of proportional changes in maritime traffic, the predicted relative risk of mortality from a ship strike in the areas of greatest concern would increase 1.2 to 1.8 times for humpback whales in the next one to two decades and 1.3 to 2.5 times for fin whales.

Sources of Uncertainty

The Generalized Additive Models used to estimate a gradient of predicted whale density in the study area were relatively simple, as they relied on only two (humpback whales) and one (fin whales) static physical covariates. The absence of time-varying environmental variables and other independent datasets of humpback and fin whale distribution in this area added uncertainty to the predicted relative density. Further study is needed to increase sightings and effort to further quantify distribution and movements of whales, including on a finer scale to further refine identification of high risk areas.

The predicted humpback and fin whale densities are likely underestimates because we were unable to correct the survey estimates for missed animals resulting from either availability bias (diving whales that were underwater, and thus unavailable for observers to detect), or from perception bias (whales that were available at the surface for observers to detect, but were not

seen due to environmental conditions, fatigue, etc.). This means that predictions of relative lethal strike risk calculated from the model-estimated whale densities are considered to be conservative.

Surveys were not conducted in every month. Therefore, we could not identify seasonal variations in the density and distribution of whales or marine traffic, both of which might impact ship strike risk. Humpback whales are migratory, and are most abundant in BC between May and November, although some animals remain year-round. In contrast, fin whales are thought to be year-round occupants. In addition to seasonal differences in abundance, there may also be seasonal differences in whale behaviour (e.g., feeding effort) that can also increase their vulnerability to ship strikes. The model of ship strike risk also did not take into account species-specific vulnerability.

Estimates of future ship strike risk were conservative because potential whale population growth was not taken into account, nor were changes in the risk of mortality from ship strikes that may result from increasing ship size. Cargo and container ship sizes have doubled since 2000 and are expected to continue to grow.

Projected future ship traffic was also assumed to maintain the existing ship routing and thus only increase in intensity on the same trajectories. Furthermore, future projections were estimates of the increased number of ships, categorized by type and speed class. However, it is possible that the trend in future shipping could be towards fewer but larger ships, and it is not known whether this would result in greater or lesser speed.

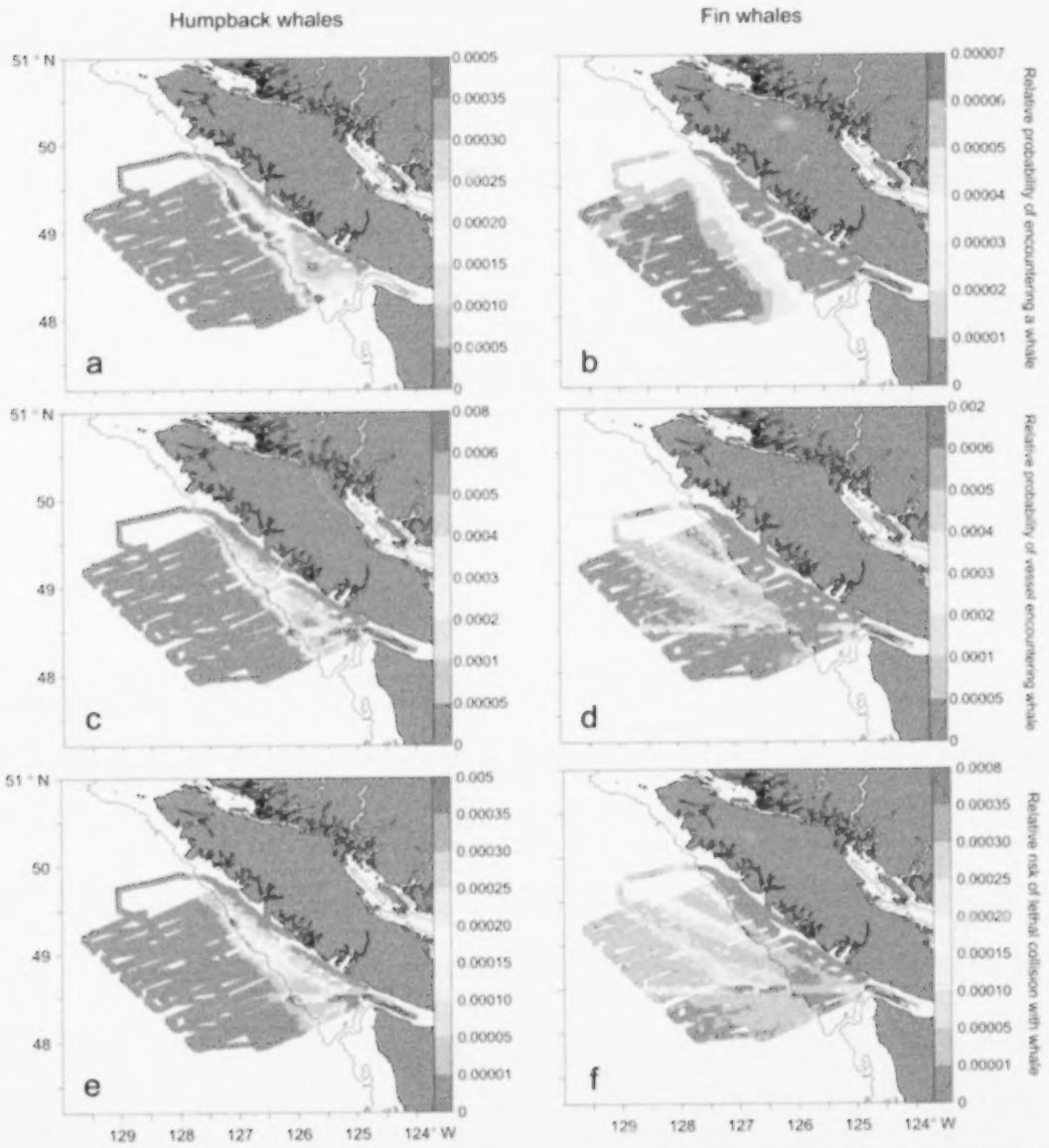

Figure 3. Aerial survey study area off the west coast of Vancouver Island, BC, Canada, divided into 1 km^2 grid cells (N=23,996). Filled cells indicate those containing survey effort that was retained for analysis. Colours indicate the relative probability of (a,b) encountering a humpback or fin whale (calculated from GAM model estimates of whale densities), (c,d) a vessel encountering a humpback or fin whale, and (e,f) the relative risk of a lethal collision between a vessel and a humpback or fin whale; 2013 AIS ship traffic dataset. The continental shelf break is illustrated by the 200 m bathymetric contour (black line). Colour bars for (c), (d), and Fig. 1 are scaled similarly to facilitate comparisons, as are colour bars for (e) and (f). Note that colour bar increments for the lowest and/or highest categories are not necessarily placed at equivalent intervals, to allow for more detailed visualization of the majority of the data range.

CONCLUSIONS AND ADVICE

The study demonstrated that there are areas off the southwest coast of Vancouver Island where it is expected that there is risk of collision and mortality for large baleen whales from ships. Spatial distributions of whale densities (estimated with Generalized Additive Models) generally corroborate existing information about humpback and fin whale distributions in British Columbia.

This study is the first of its kind on the west coast of Vancouver Island. The relative risk of a ship strike was estimated to be low even in the areas of greatest risk (less than 1%), although it is probable that the models underestimate the risk because the model derived whale density estimates are likely conservative. Model predictions could be further refined by incorporating species-specific vulnerabilities and possibly seasonal changes in distribution. The impact of ship strikes cannot be fully understood until abundance estimates are available for fin whales and humpback whales off the west coast of Vancouver Island.

Overall, it is reasonable to expect that the risk of ship strikes will increase in the study area as a result of greater traffic, larger ship sizes, and growing whale populations.

Further study is needed to increase systematic survey effort off the west coast of Vancouver Island to improve estimates of species densities and distributions, and to allow for a seasonal analysis of ship strike risk. Studies using methods to understand fine scale habitat use and behaviour are also needed to further refine identification of areas of greatest ship strike risk.

SOURCES OF INFORMATION

This Science Advisory Report is from the February 23-26, 2016 National Marine Mammal Peer Review Committee (NMMPRC): Part II. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Conn, P. B. and G. K. Silber. 2013. Vessel speed restrictions reduce risk of collision-related mortality for North Atlantic right whales. Ecosphere **4**:1-15.

Silber, G. K., Slutsky, J., and Bettridge, S. 2010. Hydrodynamics of a ship/whale collision. J. Exp. Mar. Biol. Ecol. 391:10-19.

Simard, Y., N. Roy, S. Giard and M. Yayla. 2014. Canadian Year-round Shipping Traffic Atlas for 2013: Volume 3, West Coast. Canadian Technical Report of Fisheries and Aquatic Sciences 3091. xviii + 327 pp.

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